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COMPARING PARAMETRIC OPTIMIZATION OF THE MACHINING PARAMETERS OF AL2024-SIC FOR MRR USING TAGUCHI AND APPLIED STATISTICAL PLOTS

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ABSTRACT

In today's competitive world, the industries should have production systems which are capable of versatility, high production rate, precision and ability to produce highly finished goods. Due to this the value of input machining parameters responsible for the desired material removal rate becomes critical. In this thesis an experimental study is done in order to optimize and analyze the effects of process parameters in CNC end milling of Al 2024-SiC work material on material removal rate. Four machining parameters cutting speed, feed rate, depth of cut and number of flutes of the end mills are used. The experimentation plan is based upon the design matrix as per the Taguchi optimization technique's orthogonal arrays. The predicted values of the output responses are calculated with the help of Minitab-14 software. The results are also verified with the help of confirmation experiments. The experiment is conducted by Al 2024-SiCp stir cast plates. The processing of the job is done by solid carbide two, three and four fluted ends-mill tools under finishing conditions. The experimental matrices are designed using an L-27 orthogonal array as suggested by Taguchi methodology and the analysis of variance (ANOVA) for analyzing the performance characteristics.

KEYWORDS: End Milling, Taguchi Optimization, ANOVA & Material Removal Rate

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Original Article

INTRODUCTION

The increase in demand for highly finished products has driven the manufacturing industry to continuously improve the control of the machining processes. The quality of the surface finish plays important role in various areas like Tribology, wear resistant parts, fatigue life, bearing surfaces, etc. End Milling is widely used in machine operation in manufacturing as it is very versatile and can produce complex contours. Various end milling parameters affect response outputs like the surface texture, dimensional accuracy and MRR (material removal rate) to a greater extent.

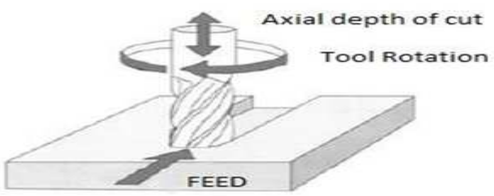

Figure 1: Experiment Run

MRR greatly influences the quality of a product and manufacturing cost. End Milling is generally applied in the aerospace industry, tool and die shops and automobile sector. Slots, pockets, peripheries, and faces of machine components can be produced by this process. The machining of aluminium metal matrix composites using CNC machines is finds diverse applications in the aeronautics industry as this industry needs high quality, better surface finish and high output rate. The operation is usually performed on a vertical milling machine. Quality and productivity are optimized with the help of optimization technique in such a manner that these multi-objectives could be fulfilled simultaneously up to the desired level.

LITERATURE REVIEW

Jasmi Hashim demonstrated that, material removal rate (MRR) is the very crucial control factor in the machining operation of production management, useful for production planners. A. Ravikiran et al. demonstrated that, material removal rate is directly linked to productivity. H.S. Lu et al (2008), investigated the effect of optimal cutting parameter design of cutting processes inside milling, for SKD61 tool steels and found that, the improvement of tool life and MRR w.r.t. From the initial machining parameters to the optimized machining parameters are 54% and 97%, respectively. The approach can effectively improve the cutting performance. U. Zuperl et al (1995), investigates the characteristic parameters in milling by using a PSO evaluation technique & found that, the MRR is improved by 28%, machining time reduced by up to 20%.

MATERIALS AND METHODS - EXPERIMENTAL PROCEDURE

A metal matrix composite is made up of two constituents, namely matrix and reinforcement. The matrix material is generally metal and the reinforcement is generally inorganic or organic compound. Here we have used silicon carbide as reinforcement as it enhances the thermal resistance of the composite making its structure more stable for machining operation and after use. In order to get the desired properties the volume of reinforcement, the shape of the reinforcement, production method etc. can be varied. The MMC is produced with the help of stir casting.

The experimental procedure involves four stages:

- The selection of proper combination of composite material, necessary cutting tools, and required equipment,
- Data collection by conducting experiments as per the defined plan,
- The establishment of an MRR prediction model, and
- Optimization of the predictive model for better results.

The MRR of multi-point cutting tool like in end milling gives higher MRR than single point cutting tools like in case of turning. For varied applications, different MRRs are achieved due to different engagements of the cutter's section with the workpiece. The Dormer catalogue shows these applications with simple icons. The volume removed by machining is the initial volume/mass of the workpiece before the start of machining minus the final volume/mass of the workpiece after machining is over. The cutting time is the time taken by the tool to move through the length of the workpiece.

$$MRR\left({mm^3}/{sec}\right) = \frac{[Initial\ mass\ of\ the\ plate\ (g) - Final\ mass\ of\ the\ plate\ (g)]}{Density\left(\frac{g}{mm^3}\right) x Machining\ Time\ (Sec)}$$

Design of Experiment

Experiments are designed using Taguchi method so that the effect of all the parameters could be studied with minimum possible number of experiments. The Taguchi method uses a special design of orthogonal arrays to study the entire parameter space with a small number of experiments. Signal to Noise (S/N) ratios are also calculated for analyzing the effect of machining parameters more accurately.

As per Taguchi's method, the selected orthogonal array must be greater than or equal to the total degree of freedom required for the experiment. So, an L27 orthogonal array was selected for the present work. The non-linear relationship between the process parameters can be revealed when more than two levels of the parameters are considered. Hence, each selected parameter was analyzed at three levels. The process parameters and their values at three levels are given in Table 1. Taguchi method is a robust optimization technique for optimizing process parameters in order to get the optimum conditions with least cost and minimum number of experiments and subsequent data analysis. Due to the advantages offered by this method, researchers have used this method in the milling operations. In the present study, the Taguchi design of experiments is used to investigate the effect of the machining parameters on MRR on a CNC vertical milling machine. The lower-the-better criterion for Ra and higher –the –better criterion for MRR were chosen to calculate the S/N ratio.

Quality as Par Taguchi

According to Taguchi, the quality of a manufactured product is a loss of that product incurred to the society from the time it is shipped. Financial loss or Quality loss may be given by:

$L(y) = k(y-m)^2$, Y= objective characteristic, m = target value,

k = Cost of defective product / $(\text{Tolerance})^2 = A/\Delta^2$

Taguchi Design Approach

The Taguchi technique involves reducing the variation in a process through robust design of experiments. To achieve desired product quality, Taguchi suggested a three-stage process:

- System Design
- Parameter Design
- Tolerance Design

Analysis of Variance (ANOVA)

In addition to the Signal to Noise Ratio (S/N ratio), the results have been subjected to Analysis of Variance (ANOVA) to evaluate the impact of control factors (process parameters) on MRR. In addition to the Signal to Noise Ratio (S/N ratio), the obtained results have been tested using statistical Analysis of Variance (ANOVA).

$$SN_i = log\frac{\bar{y}_i^2}{s_i^2}$$

Where $y_{i,j}$ = the measurement from *group i*, *observation-index j*.

k = number of groups, n_i = number of observations in group *I,* n = total number of observations,

This ANOVA analysis was done for a significance level of 0.05 (α), i.e., for a confidence level of 95%.

Figure 2: End Milled (Slot) Al 2024-SiC Plates

Figure 3: Takumi Vertical Machining Centre

RESULTS AND DISCUSSIONS

The microstructure of the composite material of the selected combination showed no significant difference before and after machining, thus indicating the material is stable over the selected range of speed variation.

Table 1: Level of Variables Used in the Experiment

Variables	Level 1 (Low)	Level 2	Level 3 (High)	Observed Values
	-1	0	1	
(A) Cutting Speed (RPM)	1000	2000	3000	MRR for 10 & 15 % SiC
(B) Feed (mm/min)	400	600	800	
(C) Depth of Cut (mm)	0.3	0.6	0.9	
(D) Number of Flutes	2	3	4	

Table 2: Response Table for S/N Ratios of MRR of Al2024-10% SiC Plates

Level	Speed	Feed	DOC	NFL
1	24.62	23.62	27.58	29.82
2	31.99	32.68	31.49	30.74
3	35.58	35.89	33.12	31.63
Delta (Max. - Min.)	10.96	12.27	5.54	1.8
Rank	**2**	**1**	**3**	**4**

Table 3: ANOVA Table of S/N Ratios of MRR of Al2024-10% SiC Plates

Source	DF	Seq. SS	Adj. SS	Adj. MS	F	P	% SS
Speed (A)	2	562.28	562.28	281.139	41.33	0	34.28
Feed (B)	2	729.14	729.14	364.569	53.6	0	44.45
DOC (C)	2	145.81	145.81	72.905	10.72	0.01	8.89
NFL (D)	2	14.65	14.65	7.326	1.08	0.398	0.893
A*B	4	60.12	60.12	15.031	2.21	0.184	3.66
A*C	4	51.7	51.7	12.924	1.9	0.23	3.152
A*D	4	35.64	35.64	8.909	1.31	0.365	2.172
Residual Error	6	40.81	40.81	6.802			2.488
Total	26	1640.14					100
S = 2.608 R-Sq =97.5% R-Sq(adj) = 89.24%							
Critical F-ratio F0.05,2,6= 5.14, F0.05,4,6= 4.53							
Significant factor – Feed; Sub- significant factor – Spindle speed							

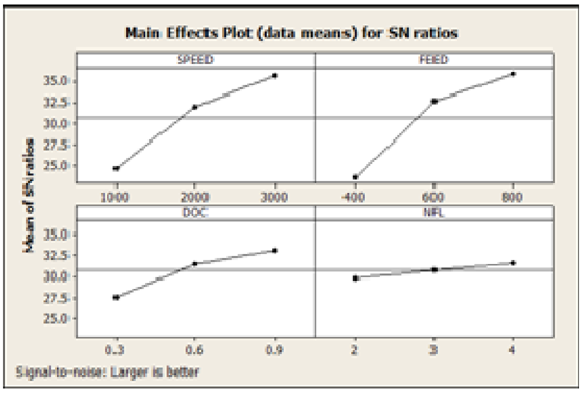

Figure 4: Main Effects Plot for SN Ratios for MRR

DISCUSSIONS ON RESULTS

Predicted material removal rate = 108.17 mm3/sec; Experimental mean MRR value for factor combination of A3-B3-C3-D1= 112.2 mm3/sec. Therefore, the optimal level of a process parameter is given by the corresponding highest S/N ratio.

Interpretation of Response Tables

S/N Ratio Table: The S/N ratio shows that the control levels, which can cope with the noise (random and uncontrollable errors) in a best possible manner. The S/N ratio may be defined as the ratio of the mean (signal) to the standard deviation (noise). S/N ratio is given by a formula having negative of logarithmic value, which is a monotonic decreasing function.

ANOVA Analysis: The ANOVA analysis (see table 3) showed that feed is the most significant factor (see in the last column %contribution of Feed is 44.45%) preceded by speed (34.28%) and depth of cut (8.89%) for getting optimal value of MRR. Interactions do not have much effect on the output response. The only interaction between feed and speed (A*B; see table) affects the MRR to some extent.

Main Effects Plots

Minitab software provides us with three main effects plots based on values of response tables, namely S/N ratio plots, data means plots and plots of standard deviations as shown below for Al2024-10%SiC.

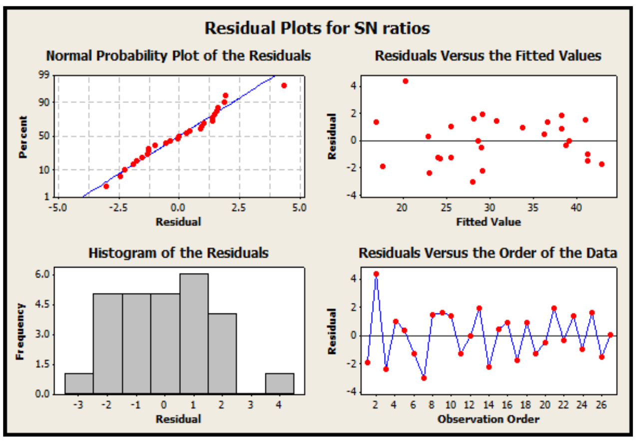

Figure 5: Residual Plots for SN ratios

Interpretation of Residual Plots

The normal probability plot of the residuals: As is clear from residual plots (Figure no. 5) residual form a straight line distribution implying model fits the data well. The normal probability plot of the response output shows that the residuals lie in a straight line indicating the errors are normally distributed.

Residuals versus the fitted values: If the assumptions are valid, plots of the residuals versus run sequence, predicted values, and other independent variables should be random and less structure. In a good regression model, the residuals from a random and normal distribution pattern. Residuals versus fitted values indicate the variance is constant and a non-linear relationship exists. The Independence of the data was tested, by plotting a graph between the residuals, and the run order for the responses confirms that there was no predictable pattern observed, because all the run residues lay on or between the levels. In the second plot of figure no. 5; fitted values vs. residuals the values are scattered randomly below and above the zero line showing data is independent.

Histograms of the residuals: Histogram shows the data is not skewed and no outliers are there. The Residuals are found to be normally distributed.

Residuals versus the order of the data: Residuals versus order of the data indicates that there are systematic effects in the data due to time or data collection order

Contour Plots

- Provides a topographical view of the predicted process output (usually modeled through a DOE) versus two of the process inputs.
- Helps to visualize the effects of two process inputs (factors) on the process output. The contours on the graph represent values of the predicted process output at various settings of the two factors on the plot.
- Used as a graphical aid when using regression, ANOVA, or DOE.
- Enter factor levels into additional columns, one for each factor. If your model has additional factors, you must specify the levels at which to hold all other factors.
- Choose Stat > DOE > Factorial > Contour/Surface Plots or choose Stat > DOE > Response Surface > Contour/Surface Plots,

The contour plots show the interaction effect of controlling parameters on MRR as depicted in Figures 6, 7, 8, 9, 10 and 11below.

Interpretation of Contour Plots

Figure 6 - Contour Plots of DOC versus NFL: Dark blue colour indicates lower MRR (< 105 mm3/Sec), while dark green colour indicates higher value of MRR (>130mm3/Sec), as shown in the table given on the side of the contour plot. Higher DOC (0.9 mm) and a higher number of flutes (4 fluted end mill cutter) results in higher MRR, as indicated by dark green colour.

Figure 7; Contour Plots of NFL versus Feed: Light green colour indicates lower MRR (<50 mm3/Sec), while dark green colour indicates higher value of MRR (>125 mm3/Sec), as shown in the table given on the side of the contour

plot. Higher feed (800 mm/min) and number of flutes (4 fluted end mill cutters) produce a better and smoother surface, i.e., lower value of MRR as indicated by light green colour.

Figure 8; Contour Plots of DOC versus Feed: Dark blue indicates lower MRR (<20 mm3/Sec), while dark green colour indicates higher MRR (>120 mm3/Sec), as shown in the table given on the side of the contour plot. Higher DOC (0.9 mm) and higher feed (800 mm/min), results in higher MRR as indicated by dark green colour.

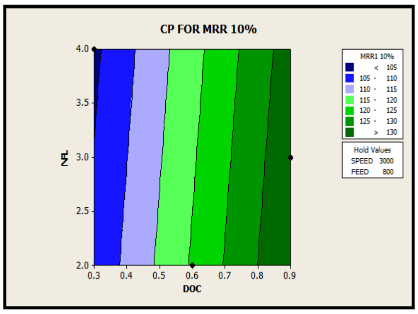

Figure 6: Contour Plots of DOC versus NFL

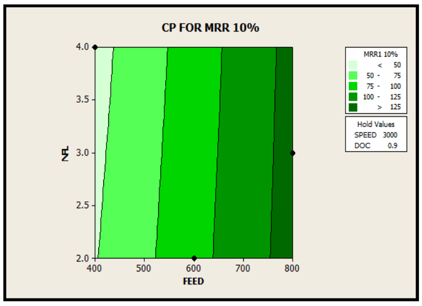

Figure 7: Contour plot for MRR of Al2024-10%SiC - FEED Vs.NFL

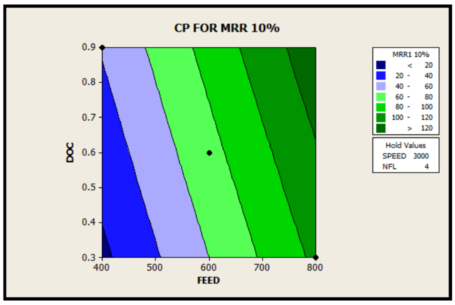

Figure 8: Contour plot for MRR of Al2024-10%SiC - DOC vs. FEED

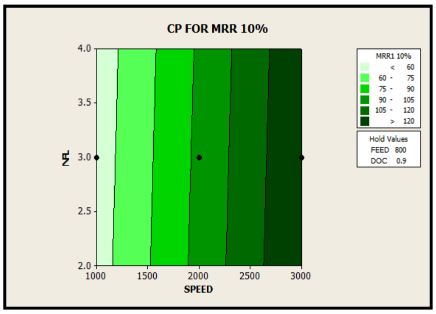

Figure 9: Contour plot for MRR of Al2024-10%SiC - SPEED vs. NFL Speed

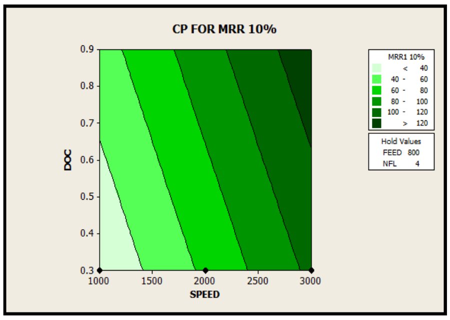

Figure 10: Contour plot for MRR of Al2024-10%SiC - DOC vs. SPEED

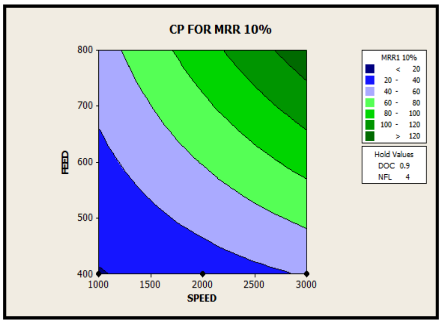

Figure 11: Contour plot for MRR of Al2024-10%SiC - SPEED vs. FEED

Figure 9; Contour Plots of NFL versus Speed: Light green colour indicates lower MRR (<60 mm^3/Sec), while dark green colour indicates higher value of MRR (>120mm^3/Sec), as shown in the table given on the side of the contour plot. Higher number of flutes (4 fluted end mill cutter) and higher speed (3000 rpm), results in higher MRR, as indicated by dark green colour.

Figure 10; Contour Plots of DOC versus Speed: Light green colour indicates lower MRR (<40mm^3/Sec), while dark green colour indicates higher value of MRR (>120 mm^3/Sec), as shown in the table given on the side of the contour plot. Higher DOC (0.9 mm) and higher speed (3000 rpm), results in higher MRR, as indicated by dark green colour.

Figure 11; Contour Plots of Speed versus Feed: Dark blue colour indicates the lower MRR value (<20mm^3/Sec), while dark green colour indicates higher value of MRR (>120mm^3/Sec), as shown in the table given on the side of the contour plot. Higher feed (800 mm/sec) and higher speed (3000 rpm), results in higher MRR, as indicated by dark green colour.

Surface Plot

- The three-dimensional surface plot helps to visualize the effects of two process inputs (factors), on the process output. The height of the surface is the predicted process output, at various settings of the two factors, included in the plot.
- Used as a graphical aid in regression, ANOVA, or DOE.
- Enter factor levels into additional columns, one for each factor. If your model has additional factors, you must specify the levels at which to hold all other factors.
- Stat > DOE > Factorial > Contour/Surface Plots or Stat > DOE > Response Surface > Contour/Surface Plots.

The 3-D surface plots for the MRR are shown in figures 12, 13, 14, 15, 16 and 17. In each of these graphs; two cutting parameters are varied, while the third parameter is held as its mid value.

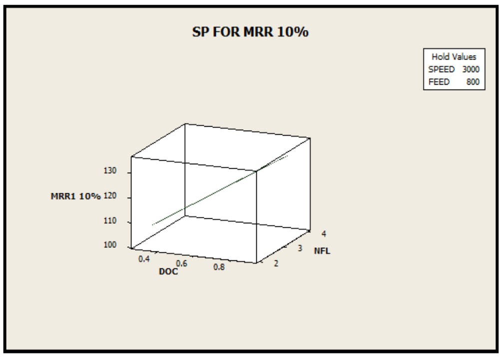

Figure 12: Surface Plot DOC versus NFL (Speed & Feed – Hold)

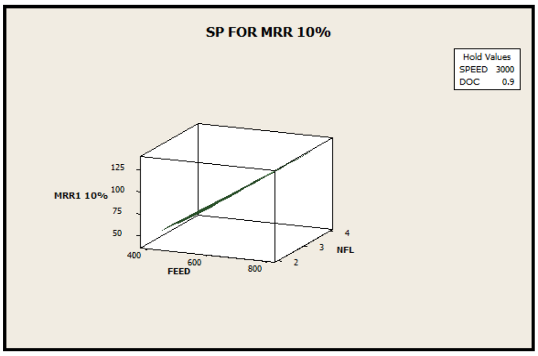

Figure 13: Surface Plot Feed versus NFL (Speed & DOC – Hold

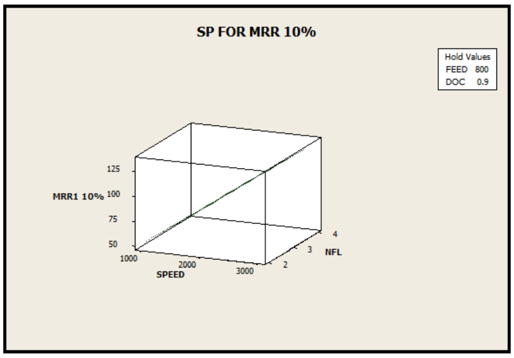

Figure 14: Surface Plot Speed versus NFL (Feed & DOC – Hold)

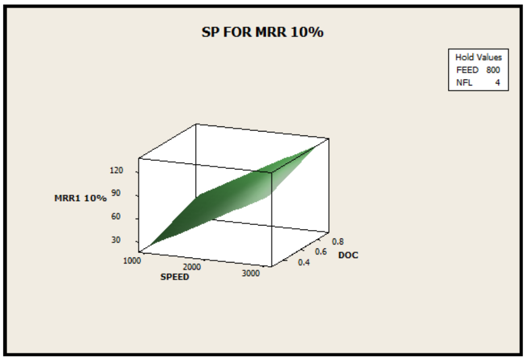

Figure 15: Surface Plot Speed versus DOC (Feed & NFL – Hold)

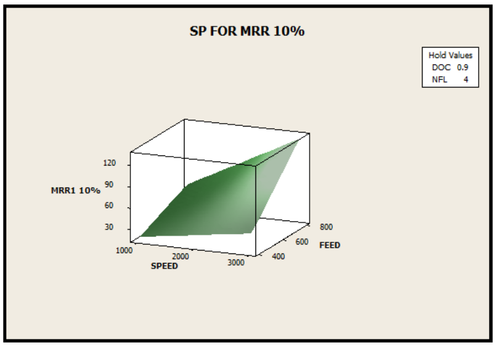

Figure 16: Surface Plot Feed versus Speed (NFL & DOC – Hold)

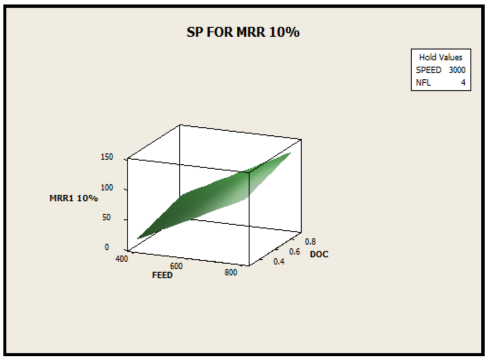

Figure 17: Surface Plot Feed versus DOC (Speed & NFL – Hold)

Interpretation of Interaction Effects of Surface Plots

From figure 12; 3-D Surface Plot-- NFL versus DOC (Feed & Speed – Hold): It is observed highest MRR, and was obtained from the combination of higher depth of cut and higher number of flutes, of the end milling tool.

From figure 13;3-D Surface Plot -- NFL versus Feed (DOC & Speed – Hold): It is observed that, highest MRR was obtained from the combination of higher feed value and higher number of flutes, of the end milling tool.

From figure 14; 3-D Surface Plot -- Speed versus NFL (DOC & Feed – Hold): It is observed that highest MRR was obtained from the combination of higher speed and higher number of flutes of the end mill cutter.

From figure 15; 3-D Surface Plot -- DOC versus Speed (NFL & Feed – Hold): It is observed that, highest MRR was obtained from the combination of higher DOC and higher speed, of the end mill cutter**.**

From figure 16; 3-D Surface Plot --Speed versus Feed (DOC & NFL – Hold): It is observed that, the MRR attains a maximum value for higher feed value and higher speed of the end mill cutter. The slope of the plot, also shows the non-linear relationship of output response parameter MRR, with the combination of speed and feed.

From figure 17; 3-D Surface Plot - DOC versus Feed (NFL & Speed – Hold): It is observed that, Highest MRR was obtained with higher feed and higher DOC.

CONFIRMATION EXPERIMENT

The combination of input control factor levels, for which optimum output responses will be obtained, is given in table 4, which shows the results of the confirmation test, with optimized input control factors for output responses namely MRR. The verification between the predicted values and experimental data, for both MMCs is in good agreement for a

95% confidence level.

Table 4: Confirmation Test Results

Expt No.	Spindle speed	Feed	Depth of cut	No. of flutes	MRR (mm3/sec)	
					10% SiC	15% SiC
1	3000	800	0.9	2	112.2	----
2	3000	800	0.9	2	-----	133.8

The above table, shows the results of the confirmation test with optimized input control factors, for output responses namely MRR. The verification between the predicted values and experimental data, for both MMCs is in good agreement for a 95% confidence level. A minor difference between the trial value and calculated value, could be assigned to the presence of random errors and different environmental parameters.

CONCLUSIONS

The optimization has been done to reduce surface roughness. From this study it can be concluded that:

- ANOVA and S/N plots reveal that the speed is the dominant parameter followed by the depth of cut and feed.
- Contour and surface plots also revealed that, the feed rate and spindle speed are by far the most dominant factor, than the depth of cut for MRR.
- In end milling, increase in cutting speed, increases in feed rate and an increase in depth of cut will increase the MRR, within specified test range. The feed rate and cutting speed is by far, the most dominant factor than the depth of cut for material removal rate.
- The values of same control factors for Al2024-15%SiC are high cutting speed (3000 rpm), high feed rate (800 mm/min.) and high depth of cut (0.9 mm) and four fluted end mills.
- As the content of Silicon carbide increases in the aluminum alloy, end mill with more flutes provides better material removal.

REFERENCES

1. *F.A.Girot, J.M. Quenisset & R.Naslai, (1987): Composite Science Tech., Vol.30, p. 155.*
2. *Guillem Quintana, Joaquim Ciurana, Daniel Teixidor, (2008) "A New Experimental Methodology For Identification Of Stability Lobes Diagram In Milling Operations" International Journal Of Machine Tools & Manufacture 481637- 1645.*
3. *H. Basak, H.H. Goktas, (2008)" Burnishing Process On Al-Alloy And Optimization Of Surface Roughness And Surface Hardness By Fuzzy Logic", Technical Education Faculty, Mechanical Education Department, Bes_ Evler, 06500 Ankara, Turkey.*
4. *H. Cao, X. Chen, Y. Zia, F. Ding, H. Chen, J. Tan, Z. He, (2008)" End Milling Tool Breakage Detection Using Lifting Scheme and Mahalanobis Distance", International Journal of Machine Tools & Mfg. pp141-151.*
5. *Kromanis, A.; Krizbergs, (2008) "3d Surface Roughness Prediction Technique in End Milling Using Regression Analysis", Tallinn, Estonia Industrial Engineering.*
6. *Luo Shourjing, Jiang ju fu, Weng ying, Teng dong dong, Zu lijun Trans (Feb. 2003): "Interface & microstructure characteristics of SiC2024 aluminum" Nonferrous met. Soc. China, Vol.13,no.l*

7. *Metin Kok , Kahramanmaras , Sutcu Imam (2006): A study on the Machinability of Al203 particle reinforced Aluminum alloy composite ,IIBC, 11th International inorganic bonded fiber composite conference, Nov.5-7, Madrid- Spain*

APPENDICES

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